JAMES J. McGRATH
P.Eng.

Open File Report 87-11

CUSTOM MILL OPTIONS FOR NEW BRUNSWICK COMPLEX SULPHIDE ORES

by

James J. McGrath, P.Eng.

Canada-New Brunswick Mineral Development Agreement
Entente Canada-Nouveau-Brunswick L'Exploitation Minérale

Natural Resources and Energy New Brunswick
Ressources Naturelles et Énergie Nouveau-Brunswick
Energy, Mines and Resources Canada
Énergie, Mines et Ressources Canada

87-03836/

This report has been prepared for:

Minerals and Energy Division
Department of Natural Resources and Energy
New Brunswick

Hon. Malcolm N. MacLeod, Minister

1987

CUSTOM MILL OPTIONS FOR NEW BRUNSWICK COMPLEX SULPHIDE ORES

This project was funded under the Canada-New Brunswick Mineral Development Agreement, a subsidiary agreement under the Economic and Regional Development Agreement.

Copies available by contacting:

Minerals and Energy Division
Department of Natural Resources
and Energy
P. O. Box 6000, Fredericton
New Brunswick E3B 5H1

1987

Report No.: Open File Report 87-11

Author: James J. McGrath, P.Eng.

Catalogue No.: ISSN 0712-4562

Custom Mill Options for New Brunswick Complex Sulphide Ores

A Report Prepared for the
Process Studies Group
Mineral Development Branch
New Brunswick Department of
Natural Resources and Energy

by

James J. McGrath, P.Eng.

March 31, 1987

Custom Mill Options for New Brunswick Complex Sulphide Ores

Abstract

A review of current mineral beneficiation and processing literature was conducted to determine the extent of published data available on treatment of complex sulphide ores. Over 100 titles were reviewed of which 21 are referenced. The material has been summarized in accordance with beneficiation and extraction technology and the findings demonstrate that the most probable route for a custom mill in New Brunswick is through the production of bulk concentrates with processing by one or more of the developing add-on extraction technologies.

Acknowledgements and Disclaimer

This report has been prepared on behalf of the New Brunswick Department of Natural Resources and Energy. The author acknowledges the guidance and assistance of J. Dean Thibault as well as other staff of the Mineral Development Branch in its preparation.

The Department of Natural Resources and Energy is not responsible for the accuracy of the statements made or opinions expressed in this report and neither the Department nor the author assume liability with respect to any damage or loss incurred as a result of the use made of information contained in this publication.

Custom Mill Options for New Brunswick Complex Sulphide Ores

Table of Contents

		Page
i	Abstract	
ii	Table of Contents	
1.	Introduction	1
2.	Objectives	2
3.	Ore Limitations	3
4.	Beneficiation	4
	4.1 Selective Flotation	4
	4.2 Bulk Flotation	7
	4.3 Combined Bulk Flotation	9
	4.4 Summary	10
5.	Extraction Processes	10
	5.1 Selective Concentrates	12
	5.2 Bulk Concentrates	16
	5.3 Combined Bulk Concentrates	18
	5.4 Summary	20
6.	Conclusions	21
	6.1 Beneficiation	21
	6.2 Extraction	23
7.	Recommendations	27
8.	References	29
9.	Bibliography	31

List of Figures: Page

Figure I - Generalized Flowsheet for Selective Flotation of Complex Sulphide Ores 5

Figure II - Generalized Flowsheet for Bulk Flotation of Complex Sulphide Ores 8

Figure III - Generalized Schematic for Production of Selective, Combined and Bulk Concentrates From New Brunswick Complex Sulphide Ores 11

Figure IV - Custom Mill Flowsheet Options for Complex Sulphide Ores 24

List of Tables:

Table I - Extraction Processes for New Brunswick Ore Concentrates 13

Table II - Development Options for New Brunswick Complex Sulphide Ores 26

Custom Mill Options for New Brunswick Complex Sulphide Ores

1. Introduction

Under the Mineral Processing Investigation Program of the Canada - New Brunswick Mineral Development Agreement, the Mineral Development Branch of the New Brunswick Department of Natural Resources and Energy have identified a project to examine the technical feasibility of custom milling New Brunswick complex sulphide ores.

The project is to include the review of current mineral processing literature and the establishment of a sound data base, the identification of processing limitations, the development of custom mill processing options and the presentation of recommendations for bench scale work leading to an optimum flowsheet for a custom mill.

An extensive literature search has been carried out utilizing the libraries of the government, the University of New Brunswick, the CANOLE search service of the National Research Council and the Dialog service in the United States. The most relevant current data has been synthesized in the following sections of this report to provide the basis for identification of the most promising custom mill options.

Processing limitations associated with New Brunswick complex sulphide ore mineralogy, beneficiation flowsheet options and metal extraction processes have been summarized and provide the basis for recommendations of bench scale development work.

---

2. Objectives

The objective of the following discussion is to examine in broad terms the mineralogical, beneficiation and processing limitations which exist for New Brunswick complex sulphide ores and to recommend a program of test work which would lead to an optimum custom milling option(s) in New Brunswick.

Definition: A custom mill in the context of this discussion means a combination of beneficiation and metal extraction processes optimally suited to the treatment of complex sulphide ores of the Brunswick - Caribou - Heath Steele types (having the range of ore grades 0.2-1.4% Cu, 1.5-4.5% Pb, 0.4-9% Zn and 0.005-0.01% Ag) and capable to producing a high grade metal or metal complex of favourable economics.

3. Ore Limitations

New Brunswick complex sulphide ores are characterized as being "fine grained" requiring fine grinding to liberate the desired minerals Cu/Pb/Zn/Ag from the pyrite matrix.[6,7,8] In general the ores comprising the New Brunswick deposits have the range of metal values shown in the foregoing definition. Because of these constraints the relationship of grade, recovery and grind is a limiting factor affecting the ability to concentrate these ores effectively.[13]

Limitation: The relationship between grade, recovery and grind presents a limitation on the beneficiation and metal extraction options available to handle complex sulphide ores.

A second major ore-related limitation arises due to the difficulty in separating copper and lead minerals from pyrites in the middling particles.[8] This process requires careful control of reagent addition to exploit the very slight difference in floatability between Cu/Pb particles and pyrite particles.

Limitation: The difficulty in separating Cu/Pb from pyrites in middling particles presents a limitation on the ability to obtain satisfactory recoveries of copper/lead concentrates in the beneficiation circuits.

4. Beneficiation Processes

Three (3) basic beneficiation flowsheets are employed for the concentration of metal values in complex sulphide ores.[3] These include;

1. Selective flotation in which individual and separate zinc, copper and lead concentrates are produced.

2. Bulk flotation in which all metal values are floated in a single concentrate.

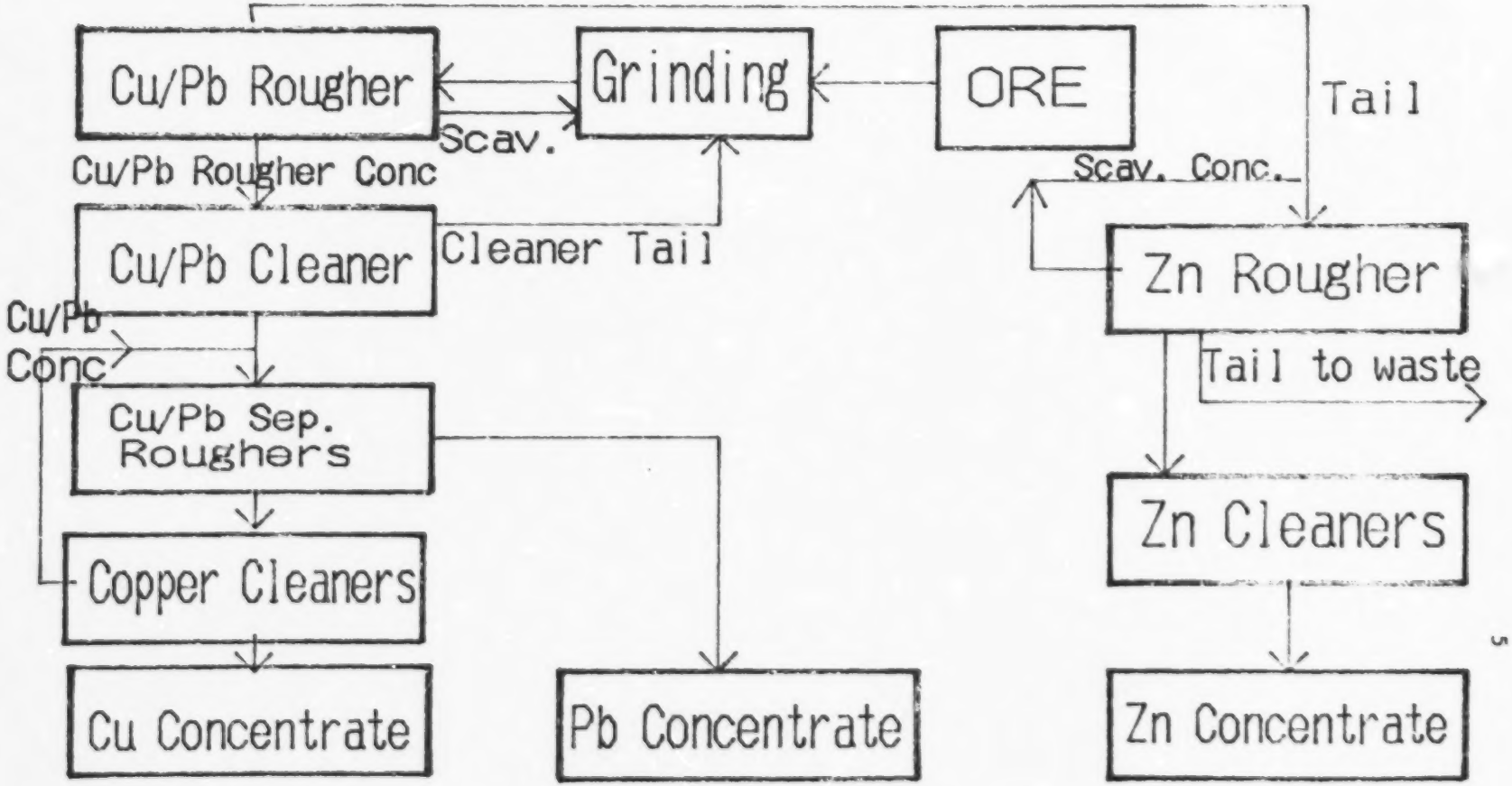
3. Combined bulk flotation in which easily separable concentrates are first produced and then a combined bulk of the remaining metals is produced to meet specific process feed requirements.

4.1 Selective Flotation

Almost all copper/lead/zinc sulphide ores are concentrated by selective flotation,[3] (Figure I), since this flowsheet produces high grade separate concentrates for later processing. Selective flotation has the following limitations:

Limitations: (a) Due to the loss of significant metal values to tailings and to other concentrates (cross contamination) the overall recovery of selective flotation is low, i.e. loss to tailings is high.

FIG I Generalized Flowsheet for Selective Flotation of Complex Sulphide Ores; from Stemerowicz and Sirois, 1983



(b) Because of the need for finer grinding to liberate Cu/Pb/Zn mineralogy particularly in Caribou ore, additional stages of flotation, more reagents, larger equipment and more filtration surface area is required and the capital and operating cost of selective flotation is high compared to bulk flotation.

(c) Special care is required in selective flotation to prevent the contamination of Zn and particularly Pb concentrates by Copper. This is particularly true for Heath Steele ore.

(d) The separation of Cu from Pb requires regrinding as noted in the ore limitation previously discussed.

4.2 Bulk Flotation

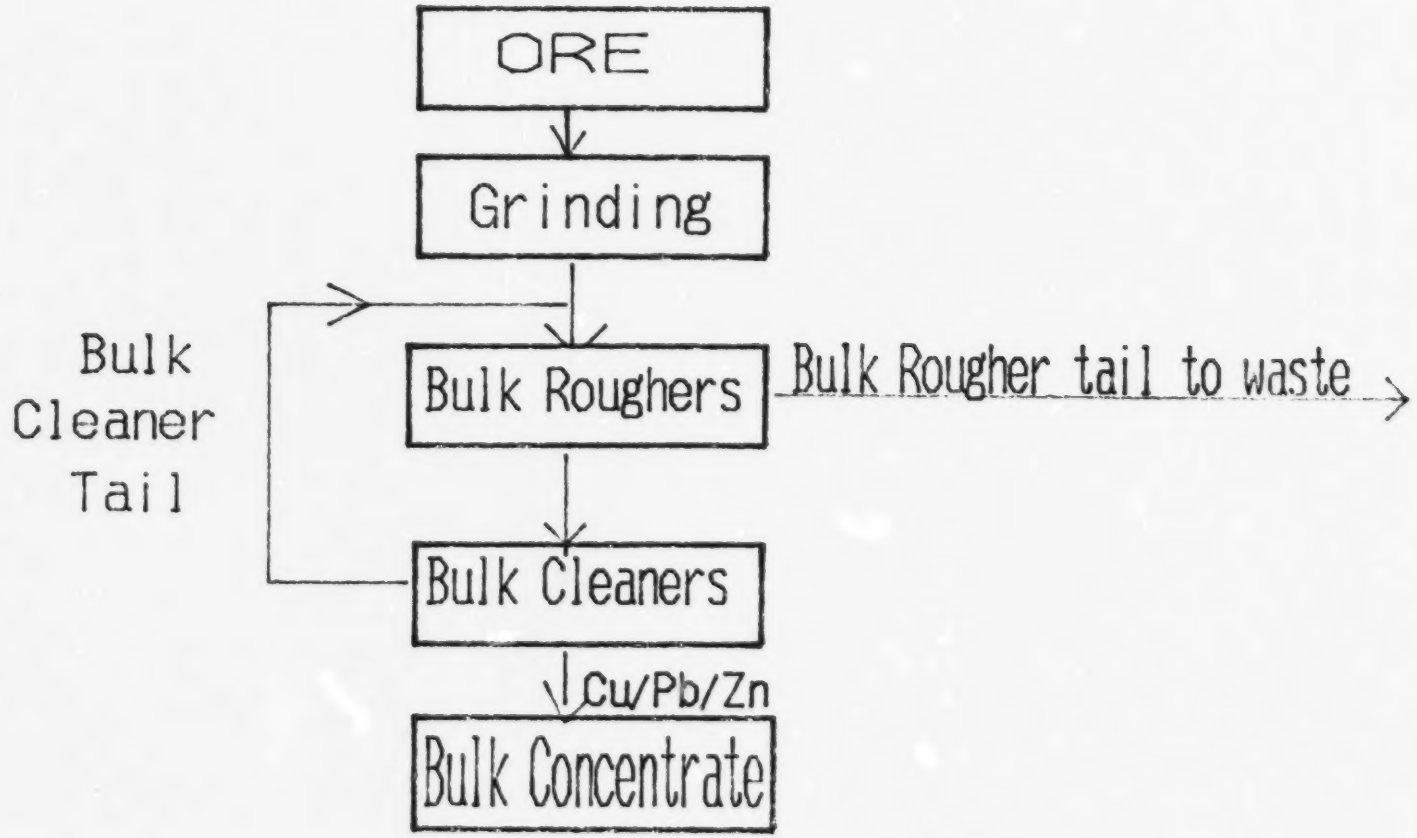
In recent years, CANMET and others have studied the prospects of bulk flotation as an alternative to selective flotation for the improvement of overall metal recovery of complex sulphide ores.[8] Bulk flotation has a simpler flowsheet than selective flotation, (Figure II), and in this regard offers capital and operating cost advantages. In addition bulk flotation does not require the fine grinding and regrinding which is associated with selective flotation and the improvement in overall valuable mineral recovery can be 20 to 30% higher, with consequent lower metal losses. One exception is Caribou ore for which only the Zinc recovery can be improved significantly.[8]

While bulk flotation is cheaper and more effective in concentrating mineral values, it nevertheless suffers from a number of limitations as follows.

Limitations: (a) Bulk concentration does not yield separate metal concentrates. All metal values are present in a single product stream.

(b) As the result of (a) above, the grade of individual metals is much lower than can be achieved with selective flotation. Bulk concentrates typically are one half (1/2) the grade of selective concentrates.

Fig II Generalized Flowsheet for bulk Flotation of Complex Sulphide Ores; from Stemerowicz, Berry, Bredin & Leigh, 1980



(c) Conventional commercial metal extraction processes applicable to low grade bulk concentrates are limited. The ISP (Imperial Smelting Process) while commercial, is hampered by the high iron content of New Brunswick pyritic concentrates.

4.3 Combined Bulk Flotation

The third flotation process available for New Brunswick ores is a combination of bulk and selective flotation known as combined bulk flotation.[1,3] Numerous combinations are possible including selective flotation with recombination of the concentrates, bulk separation of metal values with similar flotation characteristics (Cu/Pb) or exploitation of better floatability of some metal concentrates as is practiced at BMS for zinc in lead concentrates. The limitations with combined bulk processes are as follows;

Limitations: (a) Combined bulk flotation processes are either optimized for smelter requirements or as a result of the concentration process. In either case they are "custom concentrates" prepared for a specific market or due to a unique metallurgical opportunity.

(b) The capital and operating cost of combined bulk flotation generally lies between the cost of bulk and selective flotation.

(c) If easily floatable selective concentrates are produced along with bulk, very high recoveries approaching 90% are possible.[9]

4.4 Summary - Beneficiation Processes

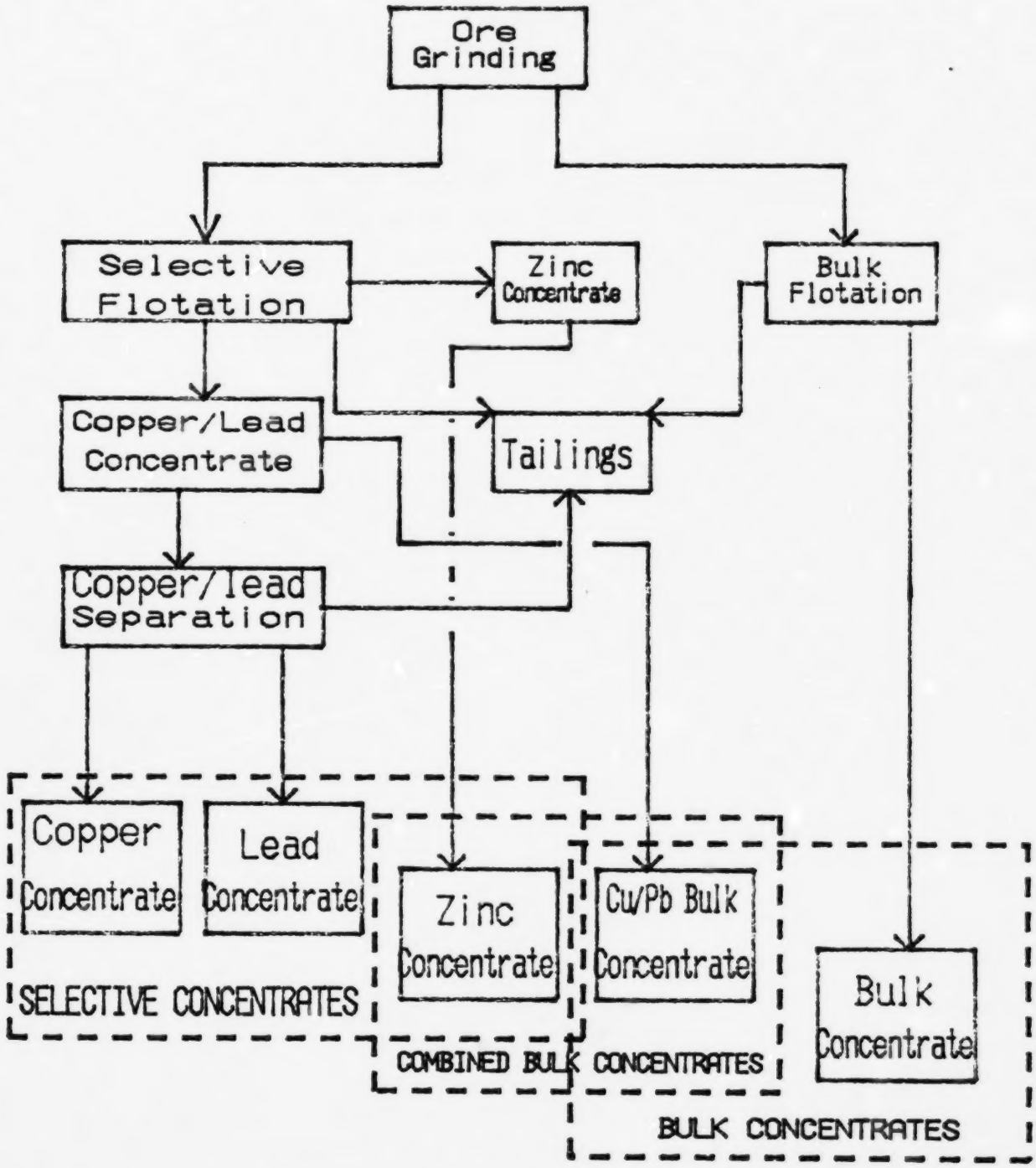
Figure III shows a flowsheet of the three beneficiation processes applicable to New Brunswick complex sulphide ores.

In general bulk flotation processes are lowest in cost and highest in metal recovery, but suffer from low grade of product. Selective processes produce high grade separate concentrates but because of losses to tailings they experience low metal recoveries. Combined processes, which are hybrids between the bulk and selective processes, have the advantage of flexibility and thus can produce optimum groupings of concentrates, usually tailored to a predetermined market. In terms of efficiency of beneficiation, it is clear that bulk flotation offers the best value overall.

5. Extraction Processes

At least twenty (20) different extraction processes exist in various stages of development from bench scale to commercial operation, which could accept as feed stock, the various concentrates discussed in the previous section, (Table 1). So as to simplify the following discussion, the processes can be examined in relation to their applicability to the three types of concentrates. Extraction processes can in general be subdivided into pyrometallurgical and hydrometallurgical processes, each with its particular set of

FIG III Generalized Schematic for Production of Selective, Combined and Bulk Concentrates from New Brunswick Complex Sulphide Ores



advantages and disadvantages. It is important to note that no single flowsheet is applicable to all ranges of metal values in N.B. ores and that iron presents a constraint on almost all processes.[5] It should be noted that while some extraction processes are commercial, many have only been demonstrated at the pilot or bench scale.

5.1 Selective Concentrates - Extraction

Currently commercial smelting or refining processes including blast furnace Lead smelting, Copper flash smelting and roast leach electrowin (RLE) for Zinc are applicable to clean concentrates. Thus the constraints in extraction processes for these concentrates are;

(a) Limited overall beneficiation/ extraction (B/E) efficiency due to low recovery in the beneficiation circuit and losses to tailings.

(b) Cross contamination of feed stock particularly by Copper in the Pb concentrate and Iron in the Zn concentrate.

(c) All selective concentrate B/E processes are energy intensive, due to the high energy usage of selective flotation combined with the energy requirement of the extraction processes.

TABLE I - Extraction Processes for New Brunswick Ore Concentrates

Class	Process	Development	Feed stock	Products	Applicability to N.B. ore	Comments
Smelting Processes	I.S.P.	Commercial	Pb/Zn Bulk	Pb, Zn	High	- Requires leach circuit for copper - Fe content of feeds problematic
	Pb Blast	Commercial	Pb Clean	Pb	High for Pb	- Process presently in use at BM&S - Not applicable to bulk concentrates
	Outokumpu Flash Smelt	Commercial	Cu Clean	Cu	Medium	- Process can be modified to feedstock - losses high in precious metals
	Hoboken	Commercial	Cu/Pb/Zn/Clean	Cu/Pb/Zn	High	- This is a custom smelter complex
	Q.S.L.	Pilot-S/Comm	Pb Clean	Pb	Medium	- Good process control, efficient low emissions
	Kivcet	Commercial	Pb/Zn Dirty	Pb/Zn	Med to High	- Product purity is poor - Forced matte circulation
Roast Leach and Electrowin	RLE	Commercial	Zn/Cu Clean	Zn/Cu	High for Zn	- Process in use by CEZ - Not applicable to Bulk Concentrates
	RPC-SRL	Pilot Scale	Zn/Cu Bulk	Zn/Cu	High for Zn	- Commercial viability depends on sulphuric acid sale. - Possible 15% Zn in feed limit
	Dowa-SRL	Commercial	Cu/Pb/Zn Bulk	Zn/Cu	Medium	- Poor Zn recovery (65%) - Copper plant design incomplete
	AMAX	Pilot Scale	Zn Dirty	Zn	Medium	- Dead Roast/Caustic Leach/Zn by Electrowinning
Pressure Leach and Solvent Extraction	Sherritt/ Cominco	Pilot Scale (Comm. for copper)	Cu/Pb/Zn Bulk	Cu/Pb/Zn	High	- Sulfur produced in elemental form - Cu/Zn based-needs additional leach for Pb/Ag
	Comprex/ Zincex	Pilot Scale (for bulk Cons)	Cu/Pb/Zn Bulk	Cu/Zn	High	- Pressure leach solvent extraction - Based on Commercial Zincex process
	Extramet	Pilot Scale	Pb Clean	Pb	Low	- Fluosilicic Acid Oxidation - Possible Cu by cementation, Zn sulfate precipitation

Class	Process	Development	Feedstock	Products	Applicability N.B. ores	Comments
Chloride Leach Processes	Elkem	Pilot Scale(Cu)	Cu/Zn Dirty	Cu possibly Zn	Low	- 2 Stage Counter Current Leach for Cu - Possible Zn by Solvent Extraction
	Clear	Commercial(Cu)	Cu Concentrate	Cu possibly Zn S.X.	Medium	- Process designed for Cu Recovery - Redox process Cu by Electrowin
	Canmet Cymet USBM	Bench Scale	Bulk Concen-centrates	Cu,Pb, Zn	High	- High recovery of all metals claimed - Solvent Extraction for Zn
	Minemet	Commercial(Zn)	Zn Conc. possibly bulk	Zn	Medium	- Basically a zinc process - No recyle of Lixiviant - Two electrowin circuits (costly)
	Chlorine Oxygen Leach	Bench Scale	Bulk Conc.	Zn	High	- Molten salt electrolysis for Zn - Cu/Pb/Ag purification needs refining
	Stairs	Unknown	Low grade Cu/Ni	Cu	Low	- HCl leach of roaster or smelter matte - Application unknown
Miscel-laneous Processes	Kennecott	Bench Scale	Cu Conc.	Cu	Low	- Nitrate leach
	Wark	Bench Scale	Bulk possibly	Zn/Cu	Low	- Little data available (proprietary)
	Technidas Reunidas	Unknown	Bulk possibly	Zn	Low	- Little data available (proprietary) - Zn by Solvent extraction and electrowin
	Dextec	Pilot Scale	Bulk Conc.	Zn/Cu	Low	- All data confidential (proprietary) - Electrolytic decomposition
	Arbiter	Unknown	Cu Conc.	Ni, Cu	Low	- N.B. ores low in Copper - Pressure Ammonia oxidation
	Bacterial	Bench Scale	Bulk Conc.	Zn/Cu/Pb	Low	- Leach times very long

TABLE I (cont'd)

Several pilot or semi-commercial techniques exist for extraction of metal values from clean concentrates. The Outokumpu Flash smelting process and the QSL process are two examples of developing technology for copper and lead smelting. For Zinc extraction most development effort has been expended in improving the existing RLE technology by developing add-on processes including Sherritt-Gordon Pressure Leach and RPC Sulphation Roast Leach. Limitations of these add-on processes are;

(a) They suffer the same overall B/E efficiency limits as conventional processes due to low recovery at the beneficiation stage.

(b) For Zinc extraction R&D emphasis has been on the improvement of existing processes to reduce the magnitude of the Jarosite iron waste disposal problem.

(c) These processes are at an intermediate stage of development and thus carry some element of risk for custom smelter application.

Summary: For selective concentrates the limitations are:

- Low metal recovery due to selective beneficiation step.

- All processes are energy intensive.

- There is small incentive to work on improving extraction processes for selective concentrates which have inherently poor metal recoveries.

5.2 Bulk Concentrates - Extraction

There are very few (perhaps only one) processes which can adequately extract metal values from simple bulk concentrates and which are at the commercial stage of development.[3,9]

The Imperial Smelting Process (ISP) is one which has the following limitations.

(a) The ISP process cannot handle bulk concentrates having more than about 10% Fe. Typical New Brunswick bulk concentrates could be expected to contain 20% Fe.[2]

(b) ISP has been tried on New Brunswick concentrates without success.

Numerous pilot scale or semi commercial processes exist for bulk concentrates including RPC-SRL, and Zincex process, the Sherritt/Cominco and Technicas Reunidas pressure leach and the Comprex and Clear Duval Process.[1] The limitations are:

(a) Uncertainty as to true level of development (SRL, TR).

(b) Sulphation relies on an acid by product.[3]

(c) Presence of high copper in bulk concentrates poses difficulty for SRL, Sherritt, T.R., Comprex and Zincex processes.[1]

A number of pilot/bench scale processes have been proposed for extraction of metal values from bulk concentrates which are based on chloride leaching.[1,18] (Table 1). These processes have the following limitations;

(a) They are still some time away from commercial applicability.

(b) The solutions are weak and liquid balance may be a problem leading to possible high operating and energy cost.

(c) Solution regeneration is not yet fully developed for some processes.

Summary:

Thus the process limitations affecting add-on processing of bulk concentrates are:

- Presence of contaminating metals Fe for ISP, Cu for others.

- Dependence on acid by-products for economics.

- The limited state of development. (There are no extraction processes with the possible exception of ISP, currently able to treat Cu/Pb/Zn bulk concentrates as the primary feed material.)[2,3]

- Newer bench scale processes need further development.

5.3 Combined Bulk Concentrates

The array of possible add-on processes applicable to combined bulk concentrates is complex for several reasons;

(a) Combined bulks can be produced in a variety of possible flowsheet arrangements including clean Zn with Cu/Pb semi-bulk clean Cu with Zn/Pb semi-bulk and Cu/Pb and Pb/Zn semi-bulk.

(b) Combined bulk concentrates are primarily a means of optimizing the mill flowsheet to meet smelter or add-on process requirements. They are in effect customized concentrates aimed at a particular metallurgical extraction process rather than vice versa.

If the Cu/Pb semi-bulk with clean Zn concentrate is considered, the processing options include, conventional blast smelting, and several developing pyrometallurgical and hydrometallurgical processes such as Kivcet and Minemet processes.[3]. The constraints here are.

(a) Conventional blast furnace technology suffers high cost and losses to slag particularly when copper and arsenic are high.

(b) Hoboken two stage smelting and Kivcet processes are promising pyrometallurgical routes. They are complex, have substantial recycle streams and require conversion of copper/lead matte.[3]

(c) Hydromet processes including Minemet, Canmet, Dextec and BHAS are in earlier stages of development and consequent uncertainties result in this regard.

Summary:

Process limitations associated with metal extraction from combined bulk concentrates are specific to the type of bulk produced and the add-on process applied.

In general however the following limits apply to extraction of semi-bulk concentrates:

(a) No single process can solve all problems so that a selection of add-on or retrofit processes must be applied to existing smelting facilities.

(b) The flexibility required to handle all possible combined bulk concentrates is only likely to be met at two or more smelter locations. A single "ideal" combined bulk smelter proposed by RTZ[3] consisted of Cu/Pb fuming plant/Cu Flash smelter/Pb blast smelter, Zn pressure leach-electrowin plant.

5.4 Summary - Extraction Processes

The range of potential metal extraction processes available to treat bulk concentrates, selective concentrates and combined bulks of New Brunswick complex sulphide ores is considerable (Table I). For selective concentrates, established technologies have been refined such that they are reasonably efficient in the extraction stage, however the overall beneficiation/ extraction cycle continues to suffer from the poor recoveries experienced in beneficiation.

Metal extraction processes for bulk concentrates are either in the developmental stage or are restricted by the level of cross-contamination problems typical of a multi metal concentrate. Some promising new technologies do exist which could provide the basis for a custom mill concept including Sherritt Cominco and Comprex,[1,3,20] and, some proven technologies would be applicable if certain beneficiation process constraints could be removed.

Metal extraction options for combined bulk concentrates possess all of the advantages and disadvantages of selective and bulk. A significant point with respect to the extraction of metals from these is that the concentrate is more often "designed" for a particular extraction process than vice versa. Thus one approach for a custom mill might be to define the best combination of extraction technology(s) and design the beneficiation flowsheet to suit the add-on technology.

6. Conclusions

6.1 Beneficiation

General conclusions can be drawn from the foregoing analysis with respect to beneficiation;

(a) All current flotation/concentration approaches have their own set of limits, therefore, the incentive exists to develop newer flotation techniques

including reverse flotation (pyrite float) to reduce Fe levels in concentrates or column float to improve Cu/Pb separation.

(b) The high cost of energy in New Brunswick dictates that low energy beneficiation (and extraction) processes must be preferred over higher energy processes. This leads the R & D effort to lower grinding, capital and operating costs, and toward bulk flotation.

(c) While bulk flotation is attractive in terms of beneficiation cost and overall metal recovery, suitable metal extraction technologies for bulk concentrates are limited by the presence of contaminants in the feedstocks, (Fe in the case of the IS process) or, the state of technology development. (RPC-SRL or CANMET FCL.) Thus the emphasis of development work for a custom mill based on bulk concentrates will be centred on identifying suitable free standing or add on technology.

(d) Improvement of recovery or selectivity of flotation processes could enhance the marketability of selective or combined bulk concentrates regardless of the add-on or downstream process(es) selected. There is incentive to improve existing beneficiation processes by examining circuit limitations or bottlenecks.

(e) Flotation process improvements, such as energy reduction and higher selectivity between metals are good prospects for investigation which could assist in defining a custom mill concentrate.

6.2 Extraction

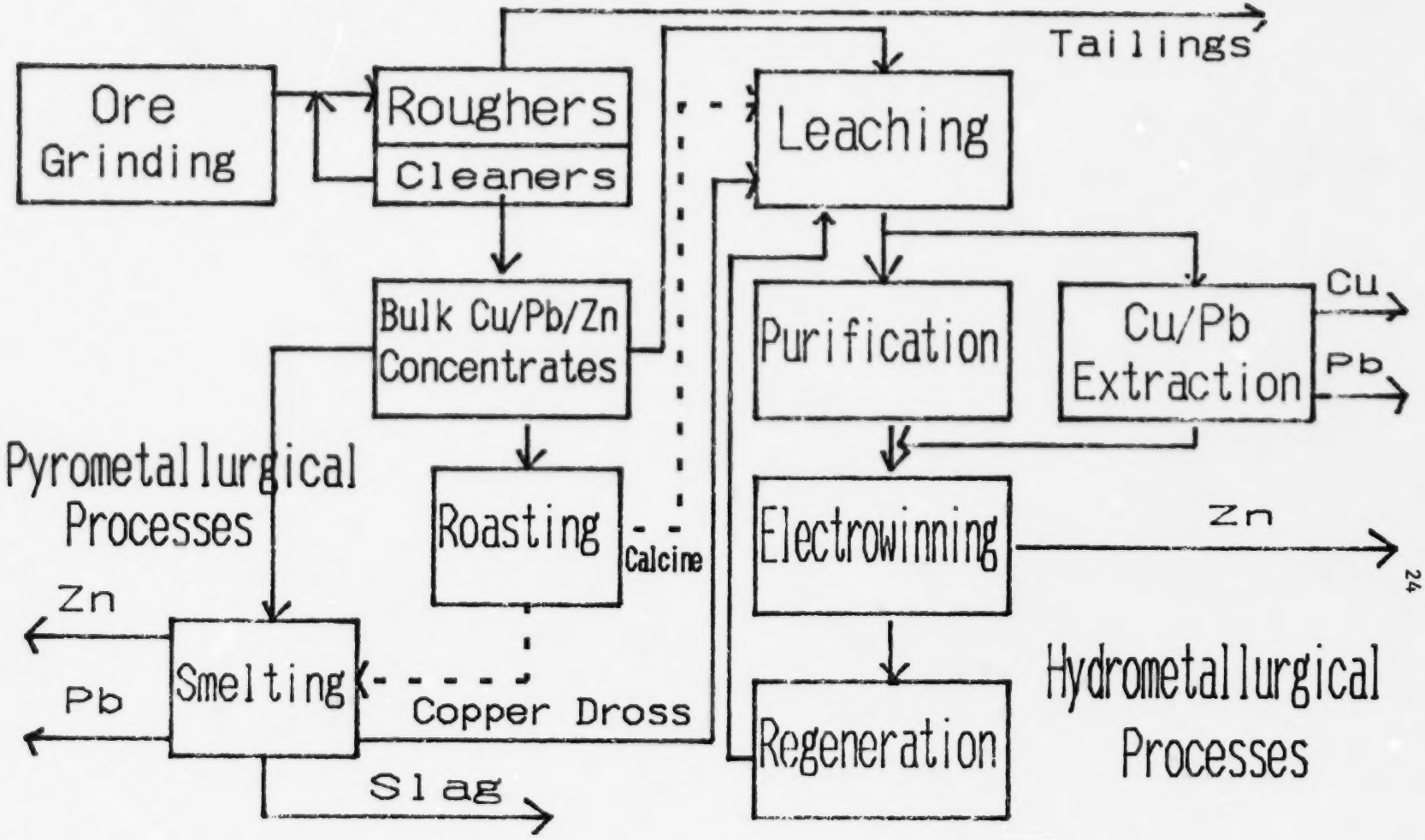
The following conclusions may be drawn with respect to metal extraction processes; (Figure IV)

(a) A custom mill concept based on selective concentrates is likely to utilize current metal extraction processes and perhaps incorporate some aspects of newer technology as an add-on.

(b) The overall selective flotation/ extraction process is not likely to be significantly improved by better extraction since the major inefficiency lies in the metal recovery at the beneficiation stage.

(c) No single process exists which can extract all metal values from a bulk concentrate. A custom mill concept based on bulk feedstock will require the minimization of cross contamination constraints which limit the commercial technologies (ISP for example) or the selection and evaluation of the most promising new extraction flowsheets.

FIG IV Custom Mill Flowsheet Options For Complex Sulphide Ores



(d) Custom mill extraction processes for combined bulk concentrates will need to be developed by matching the feed characteristics to the range of available extraction options. This may mean the simultaneous development of a custom feed for a custom extraction process, or identifying the best extraction options and designing the (custom) mill product to meet this.

Figure IV and table II summarize the development options, which are available. It is clear that the bulk concentration route incorporating either existing technology or new technology for extraction offers the best combination of opportunities for a custom mill. While marginal improvements may be possible in the production and extraction of selective concentrates, these will be made only at significant cost in both energy and additional equipment. Production of simple bulk or semi-bulk concentrates has the advantage of high recovery at low cost, which is of primary importance when considering a custom mill option in New Brunswick.

The selection of appropriate extraction technologies for application to New Brunswick bulk concentrates or semi-bulk concentrates can be based in part on the material and data base already established.

TABLE II - Development Options for New Brunswick Complex Sulphide Ores

Mineral Limitations		Beneficiation Limitations		Processing Limitations		Overall Viability
			High Capital Cost	Blast Smelt(Pb)	Poor efficiency	Commercially viable technologies but suffer from inefficiency of overall B/E processes.
	Grade/Recovery Grind Relation	Selective Flotation	High Operating Cost Low metal recovery Cu/Pb separation difficult	RLE (Zn) Minemet(Zn/Cu) Clear(Zn/Cu) Sherritt(Zn/Cu) QSL(Pb)	Iron Control High Cost Mainly Cu Processes Unproven Commercially	
Ores	Fine Grainedness of complex ore	Combined Bulk Flotation	High Capital Cost High Operating Cost Cu/Pb Separation good metal recovery Smelter/circuit specific	Kivcet RPC/DOWA SRL Minemet Comprex/Zincex ISP	UnprovenCommercially Technology uncertain High Cost Iron limit	Some processes are viable, some are marginal Overall better efficiency of B/E process.
	Cu/Pb Pyrite intimately associated	Bulk Flotation	No Separate Concentrates poor grade/ good recovery Limited extraction technology. Limited market for bulk concentrates.	ISP Kivcet RPC/DOWA SRL Sherritt Canmet/USBM Elkem	Iron Limit Unproven commercially Technology Uncertain Zn/Cu process Pilot Scale of development.	Offers best overall efficiency Limitations arise in extraction technology.

7. Recommendations

To address the limiting factors discussed in the previous section, a program of laboratory scale investigation and careful evaluation of flotation and extraction process options for a custom mill is proposed.

(a) It is proposed that the relationship of grade, recovery and grind be examined to establish an optimum level of grind required for the liberation of metal values at the Brunswick, Heath Steele and Caribou deposits. Grinding economics should be examined to allow the prediction of capital and operating costs for these components of a custom mill flowsheet. Both selective and bulk concentrating circuits should be examined.

(b) It is proposed that reagent applications be tested particularly for selective flotation circuits so as to permit the specification of optimum reagents for use in the custom mill application.

(c) It is proposed that variations on the conventional froth flotation processes as well as more recent developments such as column flotation be tested for effectiveness in copper/lead separation. This may be examined in common with grinding tests and reagent tests proposed in (a) and (b) above.

(d) A program of examination of reverse flotation or pyrite flotation is proposed as an alternative to conventional flotation techniques. This program would be aimed at reducing the iron levels in conventional metal concentrates as well as reducing the overall cost of flotation technology. The economics of reverse flotation would be carefully examined.

(e) A testing program is proposed to examine the problem of copper/lead separation in complex sulphide concentrates since this is a major flowsheet component in current selective flotation circuits.

(f) A program is proposed to examine the removal of iron from bulk concentrates since this metal is a key limiting factor in the application of ISP (Imperial Smelting Process) technology to New Brunswick bulk concentrates.

(g) Further work is recommended to assist in the identification of a suitable combination of extraction processes which could be applied to New Brunswick bulk concentrates. This would be based on the data and background already assembled for this project.

8. References

1. Barbery, G., Recent Progress in the Flotation and Hydrometallurgy of Sulfide Ores, Complex Sulphides, AIME Proceedings, 1985.

2. Bergman, A. and Haidlen, U.; Economical Aspects of Bulk and Selective Flotation Complex Sulphides, AIME Proceedings, 1985.

3. Imre, V., Castle, J.F.; RTZ Consultants, Ltd., Bristol, England, Exploitation Strategies for Complex Cu-Pb-Zn Ore Bodies., 1984.

4. Barbery, G., Fletcher, A.W., Sirois, L.L.; Complex Sulphide Ores., 1980.

5. Ozberk, E., Minto, R.; SNC Consultants Ltd., Impact of Iron Control on Process Selection., 1986.

6. Petruk, William, Schnarr, J.R.; An evaluation of the recovery of free and unliberated mineral grains, metals and trace elements in the concentrator of Brunswick Mining and Smelting Corp. Ltd., 1981.

7. Petruk, W., Chen, T.T.; Mineralogy and characteristics that affect recoveries of metals and trace elements from the ore at Heath Steele Mines, New Brunswick, 1980.

8. Stemerowicz, A.I., Sirois, L.L.; Mineral Processing Laboratory, CANMET, Energy, Mines and Resources Canada., Concentration of Complex Sulphide Ores., 1983.

9. Craigen, W.J.S., Schnarr, J.R.; Economic incentives for the production of bulk base metal sulfide concentrates., 1985.

10. Barbery, G., Engineering Aspects of Flotation in the Minerals Industry: Flotation Machines, Circuits and their Simulation.

11. Craigen, W.J.S.; CANMET, E.M.R.; Economic Incentives for the Production and Processing of Bulk Base Metal Sulphide Concentrates., 1982.

12. Stemerowicz, A.I., Leigh, G.W.; Flotation Techniques for Producing High Recovery Bulk Zn-Pb-Cu-Ag Concentrate from a New Brunswick Massive Sulphide Ore., 1978.

13. Petruk, W.; Mineralogical Evaluation of the BMS Mill Circuit., 1982.

14. Andersen, E., Boe, G.H., Danielssen, T., Finne, P.M.; Elkem-Spigerverket A/S, R&D Center, Kristiansand, Norway, Production of Base Metals From Complex Sulphide Concentrates by the Ferric Chloride Route in a Small, Continuous Pilot Plant.

15. Morizot, G., Morio, M., Cecchin; Pilot-scale Flotation of Complex Sulfide Ores.

16. Stemerowicz, A.I., Berry, T.F., Bredin, R.H., Leigh, G.W.; CANMET, E.M.R., Canada., Production of a Bulk Concentrate from Brunswick Mining and Smelting Corporation Ore in the Continuous Process Development Unit., 1980.

17. Johnston, B.H., Doyle, B.W.; Startup and Operation of the Kidd Creek Zinc Sulfide Pressure Leaching Plant., 1986.

18. Bell, P.H., EML staff. The CANMET Ferric Chloride Leach Process, an Evaluation., 1986.

19. Davey, T.R.A., Willis, G.M.; Lead Zinc and Tin - Review of Developments in 1979 and 1980., 1981.

20. Morrison, B.H.; A review of new technologies for lead and zinc reduction plants., 1984.

21. Jambor, J.L.; Mineralogy of the Caribou Massive Sulphide Deposit, Bathurst Area, New Brunswick., 1981.

9. Bibliography

Complex Sulfides
Mineralogy Reports

Petruk, W. Image Analysis Studies to Determine Liberations of Sphalerite, Chalcopyrite and Galena During Grinding of Fine Grained Pyritic Zn-Pb-Cu-Ag Ores, XVth International Mineral Processing Congress, Cannes, 1985.

Chen, T.T., and Petruk, W. Mineralogy and Characteristics that Affect Recoveries of Metals and Trace Elements from the Ore at Heath Steele Mines, New Brunswick, Canadian Mining and Metallurgical Bulletin, 73(823), 1980, pp. 167-179.

Eacott, J.G., et al, Techno-economic feasibility of zinc and lead recovery from electric arc furnace baghouse dust, CIM Bulletin, Vol. 77, No. 869, September 1984, pp. 75-81.

Wilson, J. and Petruk, W. Quantitative Mineralogy of Pine Point Tailings, Canmet, Project MRP-3.01.3.04, September 1985.

Jambor, J.L., and Laflamme, J.H.G. The Mineral Sources of Silver and their Distribution in the Caribou Massive Sulphide Deposit, Bathurst Area, New Brunswick, Canmet Report 78-14, May 1978.

Mihalik, Peter. A Quantitative Mineralogical Analysis of Mill Feed and Products from Heath Steele Mines, Extractive Metallurgy Laboratory, MP-2-6010-89, April 20, 1978.

Hughson, M.R., and Petruk, W. Distribution of Free and Unliberated Sphalerite, Chalcopyrite and Galena in Concentrates and Tailings from the Mill of Brunswick Mining and Smelting Corporation Ltd., Canmet Report 84-9E, December 1983.

Petruk, W., Pinard, R.G., and Finch, J. Relationship Between Observed Mineral Liberations in Screened Fractions and in Composite Samples, Canmet, Project MRP-3.3.0.1.03, January 1985.

Irrinki, R.R., Crouse, G.W., and Davies, J.L. Stratmat and Heath Steele N-5 Sulphide Deposits, Northumberland County, New Brunswick.

Hughson, M.R. Survey of Investigations by the Mineralogy Section of Samples from the Bathurst-Newcastle Mining Area, New Brunswick, Mineral Sciences Laboratories, MRP/MSL 75-46(TR), February 17, 1975.

New Ownership Provides Optimism for Heath Steele's Future, Engineering and Mining Journal, November 1981, pp. 153-154.

Complex Sulfides
Communition, Beneficiation

Stemerowicz, A.I. and Leigh, G.W. Flotation Techniques for Producing High-Recovery Bulk Zn-Pb-Cu-Ag Concentrate from a New Brunswick Massive Sulphide Ore, Canmet Report 79-8, August 1978.

Craigen, W.J.S. Economic Incentives for the Production and Processing of Bulk Base Metal Sulphide Concentrates, Canada/EC Seminar on the Treatment of Complex Minerals, Ottawa, Canada, October 12-14, 1982.

Maeshiro, Isamu. Recovery of Valuable Metals from 'Black Ore', Proceedings of the Eleventh Commonwealth Mining and Metallurgical Congress, Hong Kong, 1978.

Munro,P.D., Schache, I.S., Park, W.G., and Watsford, R.M.S. The Design, Construction and Commissioning of a Heavy Medium Plant for Silver-Lead-Zinc Ore Treatment - Mount Isa Mines Limited, XIV International Mineral Processing Congress, Toronto Canada, October 17-23, 1982.

Zhang, Hui-wen. New Flotation Flowsheet for Treatment of Fankov Complex Lead-Zinc Ore, Mineral Processing and Extractive Metallurgy Conference, Kunming, People's Republic of China, 27 October - 3 November, 1984.

Watson, M.D., and Botha, P.H. Mineralogical Investigation of the Ore and Plant Products as an Aid for Improved Beneficiation of the Zn-Pb-Cu Ore at Rosh Pinah, South West Africa, Spec. Publ. geol. Soc. S. Afr., 7(1983), 217-223.

Rao, G.V., Prasad, A.R., Sengupta, D.K., and Ansari, M.I. Beneficiation of a Lean Complex Sulphide Ore for Extraction of Metal Values, Journal of Mines, Metals & Fuels, XXXIIII No. 5, May 1985, pp. 221-227.

If it's there, it's Recoverable, Canadian Chemical Processing, Vol. 57, No. 10, October 1973, pp. 37-38.

Barbery, G., and Dumel, P. Energy Analysis in the Choice of Treatment Processes Examples of Complex Sulphide Ores, Industrie Minerals, Les Techniques, Vol. 5-82, April 1982.

Giegerich, H.M. Progress Report on Cominco's Red Dog project in Alaska, second largest zinc deposit ever discovered, Mining Engineering, December 1986, pp. 1097-1101.

Everett, P.K. The Dextec Copper Process, Extractive Metallurgy '81. The Institution of Mining and Metallurgy. London, pp. 149-156, 1981.

Stemerowicz, A.I., Berry, T.F., Bredin, R.H., and Leigh, G.W. Small Scale Continuous Selective Flotation of a New Brunswick Massive Sulphide Ore, Canmet Report 82-7E, April 1982.

von Wachenfeldt, G., Ideas About Selection of Plant Equipment Based on Laboratory and Pilot Plant Testing, B5 D, PP, FS.

Imre, U., and Castle, J.F. Exploitation Strategies for Complex Cu-Pb-Zn Ore bodies, Mineral Processing and Extractive Metallurgy Conference, Kunming, People's Republic of China, 27 October - 3 November, 1984.

Kennedy, A. Mineral Processing Developments at Hammaslahti, Finland. Mining Magazine, February 1985. pp. 122-129.

Bush, P.D. Plant and Equipment Practice in Base-Metal Concentrators of the M.I.M. Group of Companies, Mineral Processing and Extractive Metallurgy Conference, Kunming, People's Republic of China, 27 October - 3 November, 1984.

Makode, M.N., Rao, G.M., and Subrahmanyan, N.N. Beneficiation of a Complex Copper-Lead-Zinc Ore Sample from Askot, Pithoragarh District, Uttar Fradesh.

Forssbergh, E., and Zhai, H. Liberation Modelling of Base Metal Ores in Autogenous Grinding, Scandinavian Journal of Metallurgy, Vol. 14, 1985, pp. 9-17.

Forssbergh, E., and Zhai, H. Shape and Surface Properties of the Particles Liberated by Autogeneous Grinding, Scandinavian Journal of Metallurgy, Vol. 14, 1985, pp. 25-32.

Pearse, Geoff. Crushers and Grinding Mills, Mining Magazine, April 1986, pp. 330-331.

Gaudin, A.M., and Rush Spedden, H. Magnetic Separation of Sulphide Minerals, American Institute of Mining and Metallurgical Engineers Technical Publication No. 1549, January 1943.

Craigen, W.J.S. Economic Incentives for the Production and Processing of Bulk Base Metal Sulphide Concentrates, Canada/EC Seminar on the Treatment of Complex Minerals, Ottawa, Canada, October 12-14, 1982.

Rao, G.V., and Ansari, M.I. Ambamata Complex Sulphide Ore - Its Response for Bulk Concentrate, IM & EJ, March 1984, pp. 17-23.

Rao, A.P., and Paliwal, H.V. Research in Indian Lead Zinc Industry and Challenges of the Eighties.

Larribau, E., Detienne, J.L., and Portenseigne, G. Beneficiation and Future Exploitation of the Ore from Rouez Deposit, Chronique de la Recherche Miniere, No. 458, 1981, pp. 74-90.

Davey, T.R.A., and Willis, G.M. Lead, Zinc, and Tin - Review of Developments in 1979 and 1980, Journal of Metals, April 1981, pp. 52-66.

Wills, B.A. Mineral Processing - current problems, and future prospects, Mining Magazine, June 1986, pp. 517-521.

Istvan, G., and Walter, H. The Place of Hydrometallurgy in the Metal Winning, Banyaszati es Kohaszati Lapok-Kohaszat - 114 evf, 1981. 7 szam, pp. 313-317.

Guzman, A. Process Design for a Bolivian Complex Sulfide Ore Containing Cassiterite, Complex Sulfide Ores Conference Paper, 1980, pp. 171-17.

Rajo, J.S. and Deshpande, S.P. Role of Mineralogical Studies in Ore Dressing

Bergman, Dr. A., and Haidlen, U. Economical Aspects of Bulk and Selective Flotation.

Morizot, G., Morio, M., and Cecchin, T. Pilot-Scale Flotation of Complex Sulfide Ores.

Bartlett, Robert W. Economic Trade-Offs in Increasing Revenue from a Massive Complex Sulfide Deposit-Caribou.

Lager, T. The Rakkejaur Deposit, A Challenge to Flotation Process Technology.

de Cuypers, J. and Oudenne, P.D. Experience in the Treatment of Sulphide Ores Containing Precious Metals.

Jain, S. and Fuerstenau, D.W. Activation in the Flotation of Sphalerite.

Acid Leach

Ahmad, Y.I., Swamy, V., and Guha, D. Leaching of Metal Sulphide Ores Part II: Leaching with Oxidising Agents, Research and Industry, Vol. 28, March 1983, pp. 50-61.

Kelly, F.J. Capital and Operating Cost Estimates for the Pressure Sulphuric Acid Leach Process, Canmet, Project MRP-4.4.0.3.03, September 1980.

Bounds, Charles O. Chloride-Based Lead Extraction-Possibly an Economic Solution to the Environmental Restraints on Lead Smelting.

Shelton, R.A.J. Chloride Process Metallurgy, International Metals Reviews, September 1976, pp. 141-147.

Scheiner, B.J., and Lindstrom, R.E. Leaching Complex Sulfide Concentrates Using Aqueous Chloride Oxidation Systems, Colorado Mining Association Mining Yearbook, 1978, pp. 133-138.

Davies, D.S., Lueders, R.E., Spitz, R.A., and Frankiewicz, T.C. Nitric-Sulfuric Leach Process Improvements, Mining Engineering, August 1981, pp. 1252-1266.

Dutrizac, J.E. Jarosite-Type Compounds and their Application in the Metallurgical Industry, Hydrometallurgy Research, Development and Plant Practice Conference Proceedings, Atlanta Georgia, March 6-10, 1983.

Demopoulos, G.P., and Gefvert, D.L. Iron (III) Removal from Base Metal Electrolyte Solutions by Solvent Extraction, Canmet, Project MRP-3.4.0.2.04, March 1983.

Meixner, Michael J. The San Telmo Process - A hydrometallurgical method of recovering copper and zinc from complex sulfide ores, Erzmetall, Vol. 30, No. 5, 1977, pp. 204-208.

Anderson, W.W., Rajcevic, H.P., and Opie, W.R. Pilot Plant Operation of the Caustic Leach-Electrowin Zinc Process, The Metallurgical Society of AIME.

Letowski, Franciszek. Leaching/Flotation Processing of the Complex Sulfide Ores, Annual Meeting of the Canadian Insitute of Mining and Metallurgy, Montreal Canada, May 11-15, 1986.

Kirby, Ralph and Barclay, James. A. Extraction Processes for Low-Grade Ores, Mining Engineering, Vol. 17, No. 6, June 1975, pp. 42-47.

Hendriks, David W., and Ounpuu, MIke. Modifications to the Zinc Flotation Circuit of Brunswick Mining and Smelting Corporation Limited.

Sandberg, R.G. and Huiatt, J.L. Recovery of Silver, Gold, and Lead From a Complex Sulfide Ore Using Ferric Chloride, Thiourea, and Brine Leach Solutions, U.S. Bureau of Mines Report of Investigations, R.I. 9022, 1986.

Atkinson, G.B., Murphy, J.E., and Eisele, J.A. Purification of C12 - 02 Leach Liquors by Zinc Cementation, U.S. Bureau of Mines Report of Investigations, R.I. 8707, 1982.

Pool, D.L., Scheiner, B.J., and Hill, S.D. Recovery of Metal Values from Lead Smelter Matte by Chlorine-Oxygen Leaching, U.S. Bureau of Mines Report of Investigations, R.I. 8615, 1982.

Smyres, G.A., and Carnahan, T.G. Chlorine-Oxygen Leaching of a Low-Grade Zinc Sulfide Flotation Concentrate, U.S. Bureau of Mines Report of Investigations, R.I. 8949, 1985.

Schultze, L.E., and Bauer, D.J. Recovering Zinc-Lead Sulfide from A Geothermal Brine, U.S. Bureau of Mines Report of Investigations, R.I. 8922, 1985.

Carnahan, T.G. Effects of Temperature on Simulated In Situ Leaching of a Chalcopyrite Ore, U.S. Bureau of Mines Report of Investigations, R.I. 8642, 1982.

Lewis, Alvin. Leaching and Precipitation Technology for Gold and Silver Ores, Engineering and Mining Journal, June 1983, pp. 48-56.

Sherritt Zinc Pressure Leaching

Weir, D. Robert. Advances in Pressure Hydrometallurgy, Frontier Technology in Mineral Processing, pp. 99-112.

Scott, T.R. Continuous, Co-current, Pressure Leaching of Zinc-Lead Concentrates Under Acid Conditions, International Symposium on Hydrometallurgy, pp. 719-750.

Jambor, J.L., and Dutrizac, J.E. Beaverite-Plumbojarosite Solid Solutions, Canmet, Project MRP-3.4.0.0.04, April 1982.

The Application of the Sherritt Zinc Pressure Leaching Process to New Brunswick Zinc/Lead Bulk Concentrates Summary Report, March 22, 1978.

Ferric Chloride Leach - Bacon Donaldson, ADM

Acres Davy McKee Engineering Inc., Ferric Chloride Leaching of Sulphide Mineral Concentrates - Phase I, DSS File No. 23SQ.23440-3-9083, Contract Serial No. OSQ83-00172, ADM Contract No. C1016.00, April 12, 1984.

Bacon, Donaldson & Associates Ltd., Ferric Chloride Leaching of Sulphide Mineral Concentrates - Phase II, DSS File Number 23SQ.23440-4-9202, DSS Contract Serial No. OSQ84-00290, BDA Project No. 5371, June 1985.

Canmet Ferric Chloride

Morin, D., Gaunand, A., Renon, H. Representation of the Kinetics of Leaching of Galena by Ferric Chloride in Concentrated Sodium Chloride Solutions by a Modified Mixed Kinetics Model, Metallurgical Transactions B, Vol. 16B, March 1985, pp. 31-39.

Flett, D.S., Melling, J., and Derry, R. Chloride Hydrometallurgy for the Treatment of Complex Sulphide Ores, Warren Spring Laboratory, September 1983.

Dutrizac, J.E., and MacDonald, R.J.C. The Dissolution of Sphalerite in Ferric Chloride Solutions, Canmet, Project MRP-3.3.3.1.01, January 1978.

MacKinnon, D.J., and Brannen, J.M. Silver Cementation on Copper, Lead, and Zinc from Chloride Solutions, Canmet, Project MRP-3.4.0.0.02, November 1982.

Dutrizac, J.E. The Chloride Processing of Lead Concentrates, Canmet, Project MRP-3.4.0.2.02, April 1984.

MacKinnon, D.J., and Brannen, J.M. The Effect of Organic Additives on the Structural Characteristics of Lead Deposits Electrowon from Aqueous Chloride Electroylte, Canmet, Project MRP-3.4.0.2.02, October 1984.

Anderson, E., Boe, G.H., Danielssen, T., Finne, P.M. Production of Base Metals from complex sulfide concentrates by the ferric chloride route in a small, continuous pilot plant.

Bell, D.H., and Lucas, B.F. Ferric Chloride Leach Process - Simulated Pilot Plant Run, Canmet, Project MRP-3.0.5.2.02, October 1985.

Lucas, B.H., and Shimano, D.Y. Ferric Chloride Leach Process: Progress Report, Canmet, Project MRP-3.4.0.2.04.

Lucas, B.H., and Shimano, D.Y. Two Stage Ferric Chloride Leaching of a Pyritic Zn-Pb-Cu-Ag Bulk Concentrate, Canmet, Project MRP-3.0.5.2.02, May 1985.

Pyrometallurgy, Blast-Furnace, Flash Smelting, RPC-SRL

Hilbrans, Hermann., Gamroth, Michael., and Melcher, Gerhard. New Features and Developments in the application of the CONTOP cyclone smelting process, CIM Bulletin, Vol. 80, No. 897, January 1987.

Salter, R.S., Synnott, J., Gilders, R., Doucet, G., and Boorman, R.S. Design, Construction and Commissioning of the Demonstration Plant for the RPC Sulphation Roast Process.

Warner, N.A. Direct Smelting of Zinc-Lead Ore, Trans. Instn. Min. Metall. (Sect. C: Mineral Process. Extr. Metall.), 92, September 1983, pp. C147-C152.

Hagler, Bailly & Company and Bureau de Recherches Geologiques et Minieres, Base Metal Custom Smelting Industry: Changing Economics & Structure through 1994, November 1984.

Laguitton, D., Boire, A., Raicevic, D. Recovery of Lead and Silver from Acid Leach Residues, Canmet, Project MRP-4.3.0.3.03, June 1980.

Ruiz, J.A., Wilkomirsky, I. Modelling of Fluidized Bed Reactors for Sulfides Roasting, Control '84 Mineral/Metallurgical Processing.

Heinn, J.P., and Lectard, A. Suspension Flash Calcining: New Technology Shows Promise in Reducing Energy and Maintenance, While Improving Alumina Product, Engineering and Mining Journal, October 1983, pp. 77-83.

Floyd, J.M., and Mackey, P.J. Developments in the Pyrometallurgical Treatment of slag: a Review of Current Technology and Physical Chemistry.

Floyd, J.M., and Lightfoot, B.W. Sirosmelt and the Wide World of Opportunity: Versatile System has Downstream Possibilities at Small Mines, Engineering and Mining Journal, June 1985, pp. 52-56.

Wood, J.T. Factors Affecting the Rate of Oxidation and Removal of Ferrous Iron in Electrolytic Zinc Plant Solutions.

Cooper, P.G., and Lane, K.R. Metallurgical And Economic Modelling of a Zinc-Lead Smelter, Seventh Australian Conference on Chemical Engineering, August 22-24 1979, pp. 52-56.

Harris, C.F. and Gabb, P.J. Energy Recovery from the Zinc-Lead Blast-Furnace Process, Trans. Instn. Min. Metall. (Sect. C: Mineral Process. Extr. Metall.), 92, September 1983, pp. C153-C159.

Emery, A.C., Harris, C.F., and Robson, A.W. The Role of Zinc-Lead Blast Furnace in Processing Complex Sulphides.

Asteljoki, J., Sulanto, J., and Talonen, T.T. Outokumpu flash-smelting method and its application for nickel and lead production, Mineral Processing and Extractive Metallurgy Conference, Kunming, People's Republic of China, 27 October - 3 November 1984, pp. 171-185.